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HEADQUARTERS
QUARTERMASTER RESEARCH & ENGINEERING COMMAND
U S ARMY

TECHNICAL REPORT

ES-5

MUSKEG
REVIEW OF RESEARCH

QUARTERMASTER RESEARCH & ENGINEERING CENTER
EARTH SCIENCES DIVISION

JULY 1962

NATICK, MASSACHUSETTS

AD	Div. 2, 33	Accession No.	UNCLASSIFIED

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MUSKEG
REVIEW OF RESEARCH

William C. Robison
Arthur V. Dodd
Regional Environments Branch

Will F. Thompson
General Environments Branch

Project Reference:
7X83-01-008

July 1962

FOREWORD

Organic terrain or "muskeg", which covers vast areas of the subarctic and adjacent regions, presents special problems in both road construction and off-road travel. Development of a year-round capability for Army operations in northern regions requires special consideration of these problems. In planning its program for dealing with them, the U.S. Army Transportation Corps requested the Quartermaster Corps, under its assigned cognizance for Applied Environmental Research, to review the present state of knowledge of muskeg and to suggest possible future approaches to studying it. This report, consisting of a selected bibliography and a review of research on organic terrain in various parts of the world, is one result of the study conducted by the Quartermaster Corps. It offers a guide to past and current investigations of the subject, both theoretical and applied, for the use of those embarking on research in this field or responsible for planning and directing such research.

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ABSTRACT

Muskeg is defined and its relation to other types of soft terrain is discussed. Terms such as mire, fen, moor, moss, peatland, bog, marsh, swamp, and others are set forth as an aid in understanding the literature in other parts of the world. Systems of classification of muskeg are discussed and the Radforth system is recommended for use in classifying muskeg according to its trafficability.

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REVIEW OF RESEARCH ON MUSKEG

1. Terminology

"Muskeg" is a convenient term for a type of terrain that offers serious problems of trafficability and construction, especially in subarctic regions. The word is commonly used in Canada and Alaska, but it is subject to various interpretations and therefore must be defined at the outset of this discussion. While the Indian meaning was simply "grassy bog", it has acquired a broader connotation in modern usage. MacFarlane (1956) gives a definition that is generally accepted in Canada and will be followed in this report:

> "that terrain which is made up of a living organic mat of mosses, sedges and/or grasses (with or without tree growth) underlain by an extremely compressible mixture of partly disintegrated and decomposed organic material"

The distinctive character of muskeg is derived from the organic material, both living and dead, that it comprises. Therefore, the scientific study of muskeg has been conducted primarily by botanists. On the other hand, as a type of terrain it is also of great concern to engineers, geologists, and others who have an interest in surface and subsurface conditions. Muskeg, as a terrain type, should be distinguished from peat, which is its basic material but lacks the areal connotation of "muskeg".

Since the essential characteristic of muskeg is its constituent organic material, the term "organic terrain" has become widely used in Canada as more descriptive. It should be emphasized that muskeg or organic terrain is not the only type of terrain that causes a mobility problem in northern regions, but, as stated by Dr. W. J. Turnbull of the U.S. Army Corps of Engineers, "it constitutes one of our major trafficability problem areas."*

Muskeg reaches its maximum development in subarctic regions, where the predominant vegetation is coniferous forest. For this reason it is sometimes thought of as coextensive with the "taiga" or northern coniferous ("boreal") forest. As defined here, however, muskegs are also found both north and south of the boreal forest region. In such situations they are less extensive and commonly occur as distinct bogs (sometimes called "confined muskegs") rather than as the "peat seas" which occupy as much as 80 percent of the area in parts of the Hudson Bay Lowland (Sjörs 1959). Likewise, the "blanket bogs" that cover large areas

*Report of 2nd Conference of Tripartite Working Group on Ground Mobility, Ottawa, 1960.

in climatically maritime regions such as the Aleutian Islands and western Ireland are a type of peatland presenting the same engineering and trafficability problems as the muskeg of the boreal forest region. For this reason, and because they fall within the broader meaning of "muskeg" as defined above, they are included in this review, although the term "muskeg" is not popularly used in those treeless areas.

An understanding of the literature on muskeg--especially the writings of Europeans--requires recognition of terms that are used for similar types of terrain in other countries. Wet, peaty terrain may be called mire, fen, moor, moss, peatland, and bog in various English-speaking regions. While not entirely synonymous, all these terms are used in association with organic terrain.

Organic terrain, and often the vegetation growing on such terrain, is known in Sweden as myr (equivalent to the English "mire"), in Germany as Moor or Moos, in France as tourbière, in Poland as torfy, in Russia as boloto, and in England as bog (or, locally in northern England and southern Scotland, as moss). Swedish scientists writing in English frequently use the term mire as a general term for peaty terrain or vegetation, a practice followed by some English writers, but to many English-speaking people mire means simply "mud". The German word Moor should be avoided in English because an English "moor", in common speech, is an unenclosed wasteland, usually covered with heather, and may contain no peat whatever. Therefore the German Moor should be translated either as "bog" or "fen", depending on the particular type being discussed.

There is a similarity between the words "marsh", "swamp", "bog", "fen", and "muskeg" in that all represent wet terrain. In fact, all are sometimes used interchangeably in uncritical speech and writing. Even specialists in the study of terrain and vegetation are not entirely in agreement as to the differences between these terms (Welch 1935), but it is convenient to make a basic distinction between wetlands that have a substratum of peat (bog or muskeg) and those with a substratum of mineral soil (marsh and swamp). The latter, although undeniably a serious obstacle to cross-country movement in some places, are outside the scope of the present discussion. The word "fen" is used by many writers, especially in Great Britain, to denote a particular kind of bog in which peat is formed below the surface of water. Fens, marshes, and swamps have in common the fact that their water is telluric (i.e., comes from the ground); in a bog, on the other hand, the water may be derived partially or entirely from the atmosphere (Tansley 1939). Because of the local differences in usage, the British "fen" will be referred to here as "low bog", which is a subtype of muskeg.

2. Classification of muskeg

Many systems of classification have been proposed for the various types of muskeg, peat, and their associated vegetation. Ecologists have attempted classifications on the basis of chemical composition of the water, the plant communities, the associated terrain, and climate. These systems are discussed in detail in various references listed in the bibliography (Dachnowski-Stokes 1933, von Post 1937, Radforth 1952, and others). This section will identify the most common categories and their various designations, so that they will be recognizable regardless of the country in which they occur or the nationality of the author.

a. Physiographic and climatic categories

In most of the systems of classification that have been proposed and used, a basic distinction is apparent between two principal types of bog, referred to in German as Hochmoor and Niedermoor. These are often translated into English as "high moor" and "low moor", but because of the different connotation of "moor" in English the equivalents adopted here are "raised bog" and "low bog". The Hochmoor is not necessarily "high" in elevation; rather, the word refers to the fact that the bog is raised above the surrounding terrain and especially above the water table. The height to which it is raised above its surroundings depends on both the climate and the area covered by the bog (Gorham 1957) but rarely is it more than 6 feet. The Germans also recognize an intermediate type called "transitional" bog.

A comparison of the designations of the major types of bog used in different languages is given below (based on Spirhanzl 1937, but modified):

Language	I. Raised bog	II. Low bog	III. Transitional bog
German	Hochmoor, Moos-, Heidemoor	Grünlands-, Tal-, Flach-, Wiesen-, Niedermoor	Übergangsmoor, Mischmoor
French	Tourbières de pente	Tourbières de vallées	
Polish	Torfy wododzialowe	Torfy nizinne	Torfy przejściowe
Dutch	Hoogveen		
Swedish	Hvitmossar		
Danish		Kjaermoser	
Russian	Mochovoye boloto	Nizinnoye boloto	Perechodnoye boloto
Czech	Vrchoviště	Slatiny	Rašeliniště přechodové
English	Moss, bog	Fen	

The types of bog listed above are also distinguished in various writings according to their source of nutrients, climatic affinities, and position relative to the water table. It is helpful to recognize that these systems of classification all roughly correspond to the major categories already mentioned:

System	I. Raised bog	II. Low bog	III. Transitional bog
Weber (1902)	Oligotrophic*	Eutrophic*	Mesotrophic
von Post (1937)	Ombrogenous	Topogenous	Soligenous
Spirhanzl (1938)	Supra-aquatic	Infra-aquatic	

It should be noted here that all the terms used above (except the English) are current in the more or less continental regions of Europe, where precipitation is moderate and temperatures have a large annual variation. When the British began serious ecological study of their bogs, it became necessary to recognize an additional major category--the "blanket bog"--for bogs occupying extremely maritime sites having high precipitation. Thus in the British Isles the three major types recognized (e.g., by Tansley 1939) are "valley bog," "raised bog," and "blanket bog." These types correspond more or less to the categories recognized in Alaska by Dachnowski-Stokes (1941) as flat or "valley muskegs", "raised muskegs", and "slope muskegs". Blanket bogs are often well drained; other bogs and muskegs normally have a water table close to their surface.

b. Physiognomic classifications

For many years botanists have recognized that vegetation can be classified not only by its floristic elements but also according to its form and structure. On this basis they have divided the vegetation of the world into various "formations" or "formation-classes" such as evergreen forest and prairie. A recent restatement of these concepts has been made by Dansereau (1958), who recognized 15 structural categories based largely on earlier work by Schimper. In this system, muskegs fall either in the "needle-leaf evergreen forest" or the "meadow" type, depending upon whether or not trees are present. For a meaningful classification of muskeg, a system providing a greater degree of detail is obviously needed. The plant geographer Küchler (1949) devised a system for representing any type of vegetation by combinations of letters and has applied this system on a world-wide basis (see the Vegetation Map in Goode's World Atlas). Both this and Dansereau's system have the merit of being applicable throughout the world.

*Authorities differ in their use of these terms. Godwin (1941) considers both "eutrophic" and "oligotrophic" to be subdivisions of topogenous mires, or fens.

A method that similarly uses letter-symbols to represent the form, structure, and density of vegetation, but which is intended specifically for use in muskeg, was devised by the Canadian paleobotanist Radforth. This system assumes that the surface vegetation can indicate the subsurface conditions that determine trafficability of a given terrain, and various writings by Radforth state that this relationship has been established. The Radforth system of classification was first published in 1952 and has been summarized or reiterated in several subsequent publications by both Radforth (1955, 1956b, etc.), and MacFarlane (1958, 1959a). It has the advantage that non-technical personnel can use it, since its nine classes are identified by descriptive terms such as "woody, 5 to 15 feet high" (class B) rather than by botanical names. These basic coverage classes may be correlated with 16 types of topographic features ("contour types": hummock, mound, ridge, etc.) and with 16 subsurface categories based on the gross morphology of the underlying peat. It has been widely accepted in Canada by engineers and others who are concerned with the practical aspects of mobility over muskeg. For this reason, as well as its convenience and applicability to muskeg problems, it is recommended for classifying organic terrain according to its military significance.

3. The status of research on muskeg in Eurasia and North America

a. Eurasia

Although many Europeans have studied muskeg solely from the point of view of botany and ecological theory, most of the work has had some economic significance. In Ireland, Central Europe, and the USSR, the importance of peat as a source of fuel overshadows everything else. The possibility of reclaiming peat bogs for agriculture is also of great importance in those countries. Loss of forest land which has changed into muskeg, whether because of human disturbance or simply because of the natural trend of ecological succession, is of historic importance in the mountains of Great Britain and Ireland and is occurring today in Finland. Although many ecological studies of bogs have been made in the British Isles, study of peat as a resource has hardly begun there because (except in Ireland) the economy has long been dominated by coal. The Irish Peat Board (Bord na Mona) has planned investigations but few of their results are as yet to be found in the literature (see Barry 1954).

Central Europeans tend to study peat either as a stratified geologic deposit or from a purely botanical point of view. There is extensive literature on pollen found in peat bogs, where it is preserved as a stratified record of the vegetation of the region since the origin of the bog. However, pollen studies are largely disregarded in the Bibliography in this report because most paleobotanists have paid little attention to the general characteristics of peat bogs.

Russian research on peat and muskeg has been very intensive. Although the chief interest in peat in the USSR has been as a source of power, problems of trafficability have not been ignored. The work of the Peat Institute at Moscow, where there are 400 full-time employees and about 1,000 students, was reported briefly by Radforth at the Fourth Muskeg Research Conference (National Research Council, Canada, 1958). The Russian literature on organic terrain and its constituent vegetation and peat was summarized by S. N. Tyuremnov (1949), whose work has been abstracted and parts of it translated into English for the US Army Quartermaster Corps.

The most searching analysis of muskegs has come from Finland and Sweden. Those countries have a variety of peat accumulations unmatched elsewhere in the Old World except perhaps in the USSR, and both are vitally concerned with the relation of peat accumulation to forestry and agriculture. Consideration of muskegs as complex ecological phenomena began in Finland with the works of Cajander, Huikari, Kivinen, and Auer, and was continued brilliantly by such Swedes as von Post, Osvald, Sjörs, and Du Rietz.

b. North America

In the New World, fuel and agricultural land are abundant and except in Newfoundland peat lands have been of little commerical significance especially in high latitudes. On the other hand, economic conditions here demand that the frontier economy of the North be a machine economy, and muskeg is a barrier to the passage of machines. Studies in Canada by Radforth, MacFarlane, and others have therefore emphasized the location of vehicular routes through regions predominantly muskeg. Although ecological aspects of muskeg have not been ignored in North America (see works by Cooper, Drury, Rigg, and others), primary attention has been given to the economic problem of traffic over muskeg.

In determining the best route over muskeg, the interests of industrial firms (such as oil companies) and of the military forces coincide, for both have a vital interest in the movement of heavy equipment over roadless terrain. In addition, seasonal limitations on movement present a serious problem to both. For these reasons, the possibilities for increasing mobility by photointerpretative selection of routes over muskeg are of more than academic interest to both industry and the military. Preliminary studies of photointerpretation in muskeg regions by Stoeckeler (1949), Frost (1950), and O'Neill (1952) have been supported by the US Department of Defense. In Canada, the Muskeg Research Institute at McMaster University, Hamilton, Ontario, is preparing a series of handbooks for use as guides to airphoto interpretation from various elevations. The first two of these (Radforth 1955 and 1958), treating

interpretation of organic terrain as seen from elevations of less than 1,000 feet and from 1,000 to 5,000 feet, respectively, have been published. A third handbook, extending the range of interpretation to 30,000 feet, is in preparation.

Significant applications of airphotos to the mapping and classifying of vegetation in regions where muskeg is common have been made at McGill University by Hare (1959) and Allington (1959). Despite these efforts, the study of organic terrain from airphotos cannot be said to be entirely on a firm footing.

4. Annotated bibliography on muskeg

Muskegs, under various names, have been studied since the last decades of the 19th century, and the volume of literature devoted to them has steadily expanded in the last 20 years. A representative number of these works, including those considered to be most significant, is given. To show the range of approaches to the study of muskeg, the bibliography includes studies by botanists, engineers, and soil scientists. To show the extent of its geographical distribution, the list includes several studies in the tropics and middle latitudes as well as in high latitudes.

1. Aleksandrova, V. D. 1960. SOME REGULARITIES IN THE DISTRIBUTION OF THE VEGETATION IN THE ARCTIC TUNDRA. Arctic 13: 147-162.

A study of the vegetation of Novaya Zemlya, where bogs occur in the wettest sites, recognized as an "azonal type."

2. Allington, Kathleen R. 1959. THE BOGS OF CENTRAL LABRADOR-UNGAVA: AN EXAMINATION OF THEIR PHYSICAL CHARACTERISTICS. McGill Sub-Arctic Research Papers No. 7, McGill Univ, Montreal.

A study of muskeg in the Knob Lake area, based on photointerpretation and analysis of physiography. Classification consists of seven sub-types, the most common being string bog, sedge meadow, and spruce muskeg. Modes of origin are discussed. Good survey of the literature.

3. Anderson, M. S., S. F. Blake, and A. L. Mehring. 1951. PEAT AND MUCK IN AGRICULTURE. Cir 888, US Dept Agr, Washington.

A review of agricultural aspects of peat and peatlands. Includes an extensive bibliography.

4. Atwood, Alice Cary. 1926. PEAT; A CONTRIBUTION TOWARD A BIBLIOGRAPHY OF THE AMERICAN LITERATURE THROUGH 1925. US Dept Agr Library, Bibliogr Contrib No. 12 (mimeo), Washington.

The American literature through 1925 was scant and is now mostly obsolete.

5. Auer, Väinö. 1930. PEAT BOGS OF SOUTHEASTERN CANADA. Canada Geol Survey Memoir 162, Dept Mines, Ottawa.

A detailed stratigraphic study, noting extensive paludification of formerly well-drained land. Discusses the regional dominance of sphagnum in maritime areas and of carex inland. Mentions effect of forest fires on peat bogs.

6. ————————. 1933. DIE MOORE SUDAMERIKAS, INSBESONDERE FEUERLANDS. Handbüch der Moorkunde 7: 224-242.

A discussion of peat bogs in Tierra del Fuego.

7. ————————. 1952. PEAT LANDS. Chapter 15 in: Suomi (ed); A General Handbook on the Geography of Finland. Helsinki. (Fennia 72: 235-257.)

Classifies Finnish peat bogs; includes map showing percentage of total land area occupied by peat. Discusses various theories, especially with respect to "aapa bog" (string bog).

8. Barry, T. A. 1954. SOME CONSIDERATIONS AFFECTING THE CLASSIFICATION OF THE BOGS OF IRELAND, AND THEIR PEATS. International Peat Symposium, under auspices of Bord Na Mona (Irish Peat Board), Dublin.

Describes the principal types of peat bogs in Ireland and their relation to rainfall, relief, and climatic trends. Includes rough map showing distribution of bogs.

9. Bastin, E. E. and C. A. Davis. 1909. PEAT DEPOSITS OF MAINE. US Geol Survey Bull 376, Washington.

10. Berg, L. S. 1950. NATURAL REGIONS OF THE USSR, translated by Olga Titelbaum. Macmillan Co., New York.

Bog constitutes a very prominent element in the landscape of the forest zone of Russia, especially in northern Europe and in western Siberia. Berg distinguishes three principal types: (1) lowland (hypnum and herbaceous) bog, (2) transitional (forest bogs), and (3) sphagnum bogs.

11. Bishopp, Douglas W. 1946. ON A RECENT BOG-FLOW IN MEENACHARVY TOWNLAND, COUNTY DONEGAL. Sci Proc, Roy Dublin Soc 24: 151-156.

Describes a "landslide" of blanket-bog peat from a hilltop into a valley, a phenomenon not uncommon in Ireland.

12. Bowes, D. R. 1960. A BOG-BURST IN THE ISLE OF LEWIS. Scottish Geog Mag 76: 21-22.

A slide similar to that described by Bishopp, which released a peat-dammed lake.

13. Cajander, Aimo Kaarlo. 1902-03. EIN BEITRAG ZÜR ENTWICKLUNGS-GESCHICHTE DER NORDFINNISCHEN MOORE. Fennia 20, No. 6.

A study of the development of peat bogs in northern Finland.

14. ————. 1904-05. BEITRÄGE ZÜR KENNTNISS DES ENTWICKLUNG DER EUROPAÏSCHEN MOORE. Fennia 22, No. 3.

Compares bogs in Lappland and Bavaria.

15. ————. 1913. STUDIEN ÜBER DIE MOORE FINNLANDS. Acta Forestalia Fennica 2: 3-208.

Detailed classification, with extensive observations on factors controlling paludification.

16. Cameron, Margaret. 1947. UTILIZATION OF PEAT. Natl Research Council, Canada No.1623, Ottawa.

Describes commercial uses of peat as fuel and for many other purposes.

17. Chouard, P. and H. Prat. 1929. NOTE SUR LES TOURBIÈRES DU MASSIF DE NEOUVIELLE (HAUTES-PYRENÉES). Bull Société Botan Francaise 76: 113-130.

Remarks on peat bogs in the Pyrenees Mountains.

18. Coombs, D. B. 1952. THE HUDSON BAY LOWLAND, A GEOGRAPHICAL STUDY. M. A. Thesis, McGill Univ, Montreal.

Describes the physical geography of a muskeg-dominated area.

19. ————. 1954. THE PHYSIOGRAPHIC SUBDIVISIONS OF THE HUDSON BAY LOWLANDS SOUTH OF 60 DEGREES NORTH. Dept Mines and Tech Surveys, Geog Bull 6, Ottawa.

Distinguishes the following subdivisions: Dry Zone, Muskeg and Small Lake Zone, Marine Clay Zone, Coastal Zone. Delimits zones on a map and includes airphotos of each.

20. Cooper, William S. 1942. VEGETATION OF THE PRINCE WILLIAM SOUND REGION, ALASKA. Ecol Monographs 12: 1-22.

Muskeg of Southeastern Alaska is well described under the heading "Carex bog". Mound formation, peat dams, and invasion of forest are discussed.

21. Cuthbertson, James and N. W. Radforth. 1959. MUSKEG ACCESS: THE "SLIPE-HAUL" METHOD. Canadian Oil and Gas Industries, Oct. 1958: 49-51. Reprinted as NRC Tech Memo 58, Ottawa.

Describes a method of crossing muskeg using a vehicle in which power is applied to a previously-laid cable rather than to wheels or tracks.

22. Dachnowski, Alfred P. 1924. THE BOTANICAL COMPOSITION AND MORPHOLOGICAL FEATURES OF "HIGHMOOR" PEAT PROFILES IN MAINE. Soil Sci 17: 107-133.

23. Dachnowski-Stokes, Alfred P. 1930. PEAT PROFILES IN THE PUGET SOUND BASIN OF WASHINGTON. J Washington Acad Sci 20: 193-209.

24. ————. 1933. PEAT DEPOSITS IN USA, THEIR CHARACTERISTIC PROFILES AND CLASSIFICATION. Handbüch der Moorkunde 7: 1-140.

Recognizes 10 series of peat profiles subdivided into 49 "types", each described in detail.

25. ————. 1934. PEAT LAND UTILIZATION. Geog Rev 24: 238-250.

A brief summary of the various types of peat soils in the United States. Map shows "Regions in which the major groups of peat land occur."

26. ————. 1941. PEAT RESOURCES OF ALASKA. US Dept Agr Tech Bull 769, Washington.

Includes profiles showing stratigraphy and botanical composition of typical muskegs in several localities in Alaska.

27. Dansereau, Pierre. 1955. BIOGEOGRAPHY OF THE LAND AND INLAND WATERS. Chapter 5 in: Geography of the Northlands, ed. G.H.T. Kimble and D. Good, Am Geog Soc and John Wiley & Sons, New York.

Discusses muskeg both as a region and as a plant formation, and its relation to other northern regions and formations.

28. ———— and F. Segadas-Vianna. 1952. ECOLOGICAL STUDY OF THE PEAT BOGS OF EASTERN NORTH AMERICA. Canadian J Botany 30: 490-520.

Attempts to define difference between bogs and swamps or marshes.

29. ————————. 1958. A UNIVERSAL SYSTEM FOR RECORDING VEGETATION. Contract DA-22-079-eng-208, US Army Corps of Engineers, Vicksburg, Miss.

Vegetation of the world divided into 10 "formation-types" (including bog as "meadow") and 15 "regional climaxes". Appendix includes system for symbolic representation of all types of vegetation.

30. Daubenmire, R. F. 1953. NOTES ON THE VEGETATION OF FORESTED REGIONS OF THE FAR NORTHERN ROCKIES AND ALASKA. Northwest Sci 27: 125-138.

Discusses the association of black spruce with muskeg, noting that the organic accumulation beneath such forest is often thin.

31. Drury, William H., Jr. 1956. BOG FLATS AND PHYSIOGRAPHIC PROCESSES IN THE UPPER KUSKOQUIM RIVER REGIONS, ALASKA. Contributions from Gray Herbarium No. 178, Harvard Univ, Cambridge, Mass.

An ecological study of changes from muskeg to spruce forest and back in a permafrost region with meandering rivers. Includes a useful glossary and a thorough survey of European and American literature.

32. Dryburgh, F. B. and E. R. McKillop. 1954. CONSTRUCTION AND MAINTENANCE OF ROADS OVER PEAT. Tech Memo 29, NRCC, ACSSM, Ottawa.

A discussion of British experience in constructing low-cost roads to carry light traffic over peat in northern Scotland.

33. Du Rietz, G. E. 1949. HUVUDENHETER OCH HUVUDENGRÄNSER I SVENSK MYRVEGETATION ("Main units and main limits in Swedish mire vegetation," with English summary). Svensk Bot. Tidskr. 43: 274-309.

34. ————————. 1954. DIE MINERALBODENWASSERZEIGERGRENZE ALS GRUNDLAGE EINER NATÜRLICHEN ZWEIGLIEDERUNG DER NORD UND MITTELEUROPAISCHEN MOORE. Vegetatio 5-6: 571-585.

Makes distinction between bog and fen on the basis of presence in the latter of nutrient-bearing water from mineral ground.

35. Freeman, T. W. 1950. VEGETATION. Chapter 4 in: Ireland, Its Physical, Historical, Social and Economic Geography. London and New York.

Summarizes the character and importance of blanket bogs and other bogs in Ireland.

36. Friedland, V. M. 1951. ESSAI DE DIVISION GÉOGRAPHIQUE DES SOLS DES SYSTEMS MONTAGNEUX DE L'USSR. Pédologie 9: 521-553.

A discussion of mountain soils, including bogs, on a climatic basis. French translation of a Russian paper.

37. Frost, Robert E. 1950. EVALUATION OF SOILS AND PERMAFROST CONDITIONS IN THE TERRITORY OF ALASKA BY MEANS OF AERIAL PHOTOGRAPHS (2 vol). Engr Exprt Sta, Purdue Univ, for St. Paul District, US Army Corps of Engineers.

Photointerpretive study of Alaskan landforms, soils, and vegetation. Muskeg is discussed under "Vegetation," especially in Chapter 1. Contains numerous photographs.

38. Früh, J. and C. Schröter. 1904. DIE MOORE DER SCHWEIZ. Bern.

A study of peat bogs in Switzerland.

39. Gherassimov, D. A. 1937. ON THE PRINCIPLES OF CLASSIFICATION, SURVEYING, AND MAPPING OF PEAT DEPOSITS. Trans 6th Commission, Intl. Soc Soil Sci B: 288-292.

Presents the official system of bog survey in the USSR.

40. Godwin, H. et al. 1941. THE FACTORS WHICH DIFFERENTIATE MARSH, FEN, BOG AND HEATH. Chronica Botanica 6: 260-261.

Brief account of a discussion at the British Ecological Society points out "frequent misuse of the term 'blanket bog.'"

41. Gorham, Eville. 1957. THE DEVELOPMENT OF PEAT LANDS. Quart Rev Biol 32: 145-166.

A British biologist summarizes the effects of climatic, topographic, geologic, and biotic factors on the development of bogs.

42. Hamelin, Louis-Edmund. 1957. LES TOURBIÈRES RETICULES DU QUEBÉC-LABRADOR SUBARCTIQUE: INTERPRETATION MORPHOCLIMATIQUE. Cahiers de Géographie, Quebec.

43. Hare, F. Kenneth. 1959. A PHOTO-RECONNAISSANCE SURVEY OF LABRADOR-UNGAVA. Memoir 6, Geog Br, Dept Mines & Tech Surveys, Ottawa.

A map of vegetation types in Labrador-Ungava, with discussion and analysis. Distinguishes several types of muskeg.

44. Haught, O. L. 1952. PEAT IN TROPICAL AMERICA. Proc W Virginia Acad Sci 23: 105-107.

Describes modern peat accumulations under swamp forest in the Orinoco and middle Magdalena Valleys.

45. Hemstock, R. A. 1958. AN APPRAISAL OF MUSKEG TECHNOLOGY IN CANADA. Canadian Mining and Metal Bull, Oct 1958.

A brief survey of the problems that muskeg presents to transportation in Canada, and progress toward their solution.

46. ————. 1959a. MUSKEG - A REVIEW OF ENGINEERING PROGRESS. Paper presented at meeting of Alberta Land Surveyors, Calgary, Alberta.

A summary of the Radforth system of classifying muskeg, and a brief description of muskeg vehicles used in Canada.

47. ————. 1959b. THE MUSK-OX--CANADA'S ANSWER TO TOUGH TERRAIN. Oil and Gas J, Aug 17, 1959.

Optimistic view of potentialities of the Musk-Ox, a 20-ton-payload vehicle built for Imperial Oil for use over muskeg.

48. Henoch, W.E.S. 1960. STRING BOGS IN THE ARCTIC 400 MILES NORTH OF THE TREE-LINE. Geog J 126: 335-338.

Describes surface patterns on King William Island and Adelaide Peninsula under the name "fingerprint bog." They resemble string bogs but have permafrost, ridges of mineral material (including sand and gravel), and transgress contours. Does not state clearly whether peat is present.

49. Hopkins, David M. and R. S. Sigafoos. 1954. ROLE OF FROST THRUSTING IN THE FORMATION OF HUMMOCKS. Am J Sci 252: 55-59.

Describes the mechanism of frost action in certain New England bogs.

50. Hustich, Ilmari. 1939. NOTES ON THE CONIFEROUS FOREST AND TREE LIMIT ON THE EAST COAST OF NEWFOUNDLAND-LABRADOR. Acta Geographica v. 7.

Brief notes on bogs, bog hummocks, bog vegetation, and their distribution.

51. Iversen, J. 1934. MOORGEOLOGISCHE UNTERSUCHUNGEN AUF GRÖNLAND. Meddelelser fra Dansk Geologisk Forening, Vol. 8, No. 4.

Study of vegetation, pollen, and stratigraphy, used to throw light on the Norse occupation of Greenland and the climatic changes that brought it to an end.

52. Katz, N. J. (Nikolai Ia. Kats). 1926. SPHAGNUM BOGS OF CENTRAL RUSSIA: PHYTOSOCIOLOGY, ECOLOGY AND SUCCESSION. J Ecol 14: 177-202.

Distinguishes three principal types: (1) marsh or fen (Niedermoor), (2) transition bog (Uebergangsmoor), and (3) Sphagnum bog (Hochmoor). Sphagnum bogs are by far the most common in Central Russia, occupying thousands of square kilometers. Discusses effects of culture and fire on bogs.

53. ————. 1930. ZUR KENNTNIS DER MOORE NORDOSTEUROPAS. Botanisches Zentralblatt, Beiheft, vol. 46.

Notes on reconnaissance studies of bogs in area draining northward to the White Sea.

54. ————. 1931. ÜBER DIE TYPEN DER MOORE DER WESTSIBERISCHEN NIEDERUNG UND IHRE GEOGRAPHISCHE ZONATION. Deutsche Botanische Gesellschaft, Berichte, (1930-31) 48: 13-25.

Types of bogs in the West Siberian Lowland and their geographical zonation.

55. ————. 1932. ZUR KENNTNIS DER MOORE DES FERNEN OSTENS (KAMCHATKA). Deutsche Botanische Gesellschaft, Berichte 50: 273-288.

Results of the Kamchatka expedition of the (Soviet) Peat Institute in 1931.

56. Kivinen, Erkki. 1938. ÜBER DIE EINTEILUNG DER MOORBODEN IN FINNLAND. Trans Intl Soc Soil Sci, 6th Commission, B: 286-287.

Notes on the classification of peat soils in Finland.

57. Küchler, A. W. 1949. A PHYSIOGNOMIC CLASSIFICATION OF VEGETATION. Ann Assoc Am Geog 39: 201-210.

A simple system of classifying vegetation without using botanical categories. Can be applied to muskegs as well as other types.

58. Kulczynski, S. 1949. PEAT BOGS OF POLESIE. Mem Acad Sci, Gracovie, Classe Sci, Math, et Nat, B No 15.

A discussion of bogs in the Polesie Basin of Poland, where wooded raised bogs are the rule. (Summarized by Gorham 1957).

59. Leahey, A. 1951. A SURVEY OF THE EXTENT OF ORGANIC SOILS IN CANADA. Seminar Absts, Exptl Farm Service 1950-51. Dept Agr, Central Exptl Farm, Ottawa.

This is source of estimate that Canada has 435,000 square miles of organic soils (11.8% of the entire country).

60. Legget, Robert F. 1959. GEOLOGY AND TRANSPORTATION ROUTES. Roads and Engr Constr, Feb. 1959. Reprinted as Tech Paper 64, DBR, NRCC, Ottawa.

Includes remarks on relation of muskeg to road construction.

61. Lewis, F. J. and E. S. Dowding. 1926. THE VEGETATION AND RETROGRESSIVE CHANGES OF PEAT AREAS ("MUSKEGS") IN CENTRAL ALBERTA. J Ecol 14: 317-341.

Discusses distribution of muskegs in Central Alberta, and their degeneration as a result of climatic changes and fire.

62. MacFarlane, I. C. 1955. A PRELIMINARY ANNOTATED BIBLIOGRAPHY ON MUSKEG. Div Bldg Research, NRCC, Ottawa.

A list of 90 references, with special emphasis on road construction over muskeg.

63. ————————. 1956. TECHNIQUES OF ROAD CONSTRUCTION OVER ORGANIC TERRAIN. Roads and Engr Constr, July 1956. Reprinted as Tech Paper 45, Div Bldg Research, NRCC, Ottawa.

A well-organized review of the methods used in various countries to overcome the peculiar problems of building roads across organic terrain. Includes a good definition of muskeg.

64. ————————. 1958. GUIDE TO A FIELD DESCRIPTION OF MUSKEG. Tech Memo 44 (rev. ed.), ACSSM, NRCC, Ottawa.

A pocket summary of the Radforth system of classification, with photographs of each category.

65. ————————. 1959a. MUSKEG RESEARCH: A CANADIAN APPROACH. Tech Paper 83, Div Bldg Research, NRCC, Ottawa.

Summarizes history and current status of muskeg research in Canada.

66. ————————. 1959b. A REVIEW OF THE ENGINEERING CHARACTERISTICS OF PEAT. J Soil Mech and Foundations Div, Proc Am Soc Civil Engrs 85: 21-35. Reprinted as Tech Paper 67, Div Bldg Research, NRCC, Ottawa.

Points out existence of many gaps in knowledge of engineering properties of peat.

67. MacKenzie, J. D. 1916. GEOLOGY OF GRAHAM ISLAND, BRITISH COLUMBIA. Geol Survey Memoir 88, Canada Dept of Mines.

Includes a good description of muskeg of the kind common in southeastern Alaska.

68. Malmer, Nils and Hugo Sjörs. 1955. SOME DETERMINATIONS OF ELEMENTARY CONSTITUENTS IN MIRE PLANTS AND PEAT. Botaniska Notiser 1955: 46-80.

A study of chemical aspects of peat.

69. Meyer, Merle P. 1954. BOREAL FRINGE AREAS OF MARSH AND SWAMPLAND; Tech Rpt 2, A Photoidentification Key for the Summer (Foliage) Season; and Tech Rpt 3, A Photoidentification Key for the Winter (Non-foliage) Season. Contract Nonr-982(01). Univ Oklahoma Research Inst, Norman, Okla.

Photointerpretation keys and vegetation-type descriptions based on detailed studies in the vicinities of Ely, Park Rapids, International Falls, and Grand Rapids, Minnesota. (See also: Morris, 1954).

70. Millington, R. J. 1954. SPHAGNUM BOGS OF THE NEW ENGLAND PLATEAU, NEW SOUTH WALES. J Ecol 42: 328-344.

A study of muskegs in Australia.

71. Mollard, J. D. 1960. THE ROLE OF PHOTO INTERPRETATION IN AREAS CONTAINING MUSKEG AND PERMAFROST (mimeo). Muskeg Research Conf, Calgary, Alberta.

Stresses value of photointerpretation in planning penetration of muskeg or permafrost areas.

72. Morris, John W. 1954. BOREAL FRINGE AREAS OF MARSH AND SWAMPLAND; Tech Report 1, A General Background Study; and Tech Report 4, Final and Summary Rpt. Contract Nonr-982(01). Univ. Okla Research Inst, Norman, Okla.

A discussion of physical environment, biological environment, swamps and bogs, and transportation and communication in the boreal fringe area, based on detailed studies in the vicinities of Ely, Park Rapids, International Falls, and Grand Rapids, Minnesota. Vegetation is studied as basis for photointerpretation of terrain. (See also: Meyer, 1954).

73. Moss, E. H. 1953. MARSH AND BOG VEGETATION IN NORTHWESTERN ALBERTA. Canadian J Botany 31: 448-470.

Contains good descriptions. Discusses role of permafrost in mound formation.

74. Muller, Siemon W. 1947. PERMAFROST AND RELATED ENGINEERING PROBLEMS. J. W. Edwards Inc, Ann Arbor, Mich. Also printed as: Strategic Engr Study 62, US Army Corps of Engineers.

Contains many references to peat soil as related to permafrost. Notes differential cooling of sphagnum areas relative to normal soils because of high conductivity of peat when frozen.

75. National Research Council, Canada. Associate Committee on Soil and Snow Mechanics. PROCEEDINGS OF THE WESTERN MUSKEG RESEARCH MEETING, March 2, 1955. Tech Memo 38, Ottawa.

Includes papers on engineering properties of muskeg, access over muskeg in forestry practice, muskeg problems in Quebec highway construction, and pre-construction surveys of organic terrain.

76. ————. PROCEEDINGS OF THE EASTERN MUSKEG RESEARCH MEETING, Feb. 22, 1956. Tech Memo 42, Ottawa.

Various papers on economic applications of muskeg research in Canada.

77. ————. PROCEEDINGS OF THE THIRD MUSKEG RESEARCH CONFERENCE. Feb. 20 and 21, 1957. Tech Memo 47, Ottawa.

Papers on problems of movement over muskeg, both in summer and winter.

78. ————. PROCEEDINGS OF THE FOURTH MUSKEG RESEARCH CONFERENCE, Mar. 11, 1958. Tech Memo 54, Ottawa.

Includes sections on Muskeg Research in the USSR: Vehicles and Trafficability; Mechanical Properties of Peat; Drainage Problems.

79. ————. PROCEEDINGS OF THE FIFTH MUSKEG RESEARCH CONFERENCE, Mar. 4, 1959. Tech Memo 61, Ottawa.

Includes sections on Mechanical Properties and Road Construction; Vehicles and Trafficability; Forestry Drainage.

80. ————. PROCEEDINGS OF THE SIXTH MUSKEG RESEARCH CONFERENCE, Apr. 20 and 21, 1960. Tech Memo No. 67, Ottawa.

Includes sections on Highway Construction and Foundations; Classification and Exploration; Permafrost; and Northern Development.

81. ————. PROCEEDINGS OF THE SEVENTH MUSKEG RESEARCH CONFERENCE, Apr. 18 and 19, 1961. Tech Memo No. 71, Ottawa.

Papers largely concerned with problems of road construction over organic terrain. Others treat nature, distribution, and photointerpretation of muskeg.

82. Nuttall, C. J., Jr. and J. G. Thomson. 1960. DESIGN AND MUSKEG OPERATION OF THE 20-TON PAYLOAD CARRIER, THE MUSK-OX. Preprint for presentation at Soc Automotive Engr Natl West Coast Meeting, San Francisco.

Specifications of the "Musk-ox" and its performance on muskeg.

83. O'Neill, Hugh et al. 1952. INTERPRETATION OF VEGETATION FROM AERIAL PHOTOGRAPHY. (Mimeo) Contract N6-onr-25504, Catholic Univ Am, Washington.

A study of airphoto interpretation of arctic and subarctic regions, with special emphasis on trafficability. Includes preliminary keys. Based on test studies at Kaniapiskau River and Val David, Quebec; and Anchorage, Homer, and Unalakleet, Alaska.

84. Osbon, C. C. 1921. CLASSIFICATION AND FORMATION OF PEAT AND RELATED DEPOSITS. J Am Peat Soc 14: 37-44.

A good guide to traditional American terms and concepts. Little reference to European usage.

85. Osvald, Hugo. 1925. DIE HOCHMOORTYPEN EUROPAS. Veröffentlichen Geobotanische Institut Rübel, Zurich.

A study of raised bogs in Europe.

86. ————. 1933. VEGETATION ON THE PACIFIC COAST BOGS OF NORTH AMERICA. Acta Phytogeographica Suecica 5: 1-33.

Description and flora of bogs near Vancouver, British Columbia.

87. ————. 1949. NOTES ON THE VEGETATION OF BRITISH AND IRISH MOSSES. Acta Phytogeographica Suecica 26: 1-62.

Botanical study of British and Irish peat bogs ("mosses"). Good illustrations.

88. ————. 1954. SLOPING MIRES IN NORTHWEST NORWAY. Bot. Tidskr. 51: 274-280.

A description of bogs in the Lofoten Islands.

89. ————. 1955. THE VEGETATION OF TWO RAISED BOGS IN NORTH-EASTERN MAINE. Svensk Bot. Tidskr. 49: 110-118.

Discusses regional (climatic) differentiation of bogs in Maine.

90. Pearsall, William H. 1950. MOUNTAINS AND MOORLANDS. Collins, London.

A scholarly and highly readable account of the history and character of the blanket bogs which cover the mountains of Great Britain, and of related phenomena. Well illustrated.

91. ————. 1956. TWO BLANKET BOGS IN SUTHERLAND. J Ecol 55: 492-516.

Discusses form-evolution of bogs in the extreme north of Scotland, and their relation to salt spray as a source of nutrients.

92. Polak, B. 1946. OVER VEENONDERZOEK IN NEDERLANDSCH-INDIE. Natuurw. Tijds. Nederl.-Indie 102: 63-73.

Discusses the character, origin, and distribution of peat bogs both in the Indies and throughout the world.

93. Potzger, John E. 1953. NINETEEN BOGS FROM SOUTHERN QUEBEC. Canadian J Botany 31: 383-401.

Pollen analyses in the Gaspé and St. Lawrence Valley.

94. ————. 1956. POLLEN PROFILES AS INDICATORS IN THE HISTORY OF LAKE FILLING AND BOG FORMATION. Ecol 37: 476-483.

95. ———— and Albert Courtemanche. 1954. BOG AND LAKE STUDIES ON THE LAURENTIAN SHIELD IN MONT TREMBLANT PARK, QUEBEC. Canadian J Botany 32: 549-560.

An attempt to relate pollen profiles to climatic changes.

96. ————. 1955. PERMAFROST AND SOME CHARACTERISTICS OF BOGS AND VEGETATION OF NORTHERN QUEBEC. Rev canadienne de Géog 9: 109-114.

Account of a traverse by light plane, with bog borings at regular intervals. Average depth of peat was found to decrease northward from the St. Lawrence Valley; no muskegs found in tundra region.

97. Prescott, J. A. 1931. SOILS OF AUSTRALIA IN RELATION TO VEGETATION AND CLIMATE. Commonwealth Sci & Indust Research Organiz Bull 52, Canberra.

Reports extensive "high moor" on uplands of southeastern Australia and Tasmania.

98. Radforth, Norman W. 1952. SUGGESTED CLASSIFICATION OF MUSKEG FOR THE ENGINEER. Engr J, Nov. 1952. Reprinted as Tech Memo 24, NRCC, ACSSM, Ottawa, Jan. 1953.

Proposes a basic classification of muskeg according to 9 cover types, with full-page photographs of each. Includes classifications of topographic and subsurface features.

99. ————. 1953. THE USE OF PLANT MATERIAL IN THE RECOGNITION OF NORTHERN ORGANIC TERRAIN CHARACTERISTICS. Trans Roy Soc Canada 47 (series III): 53-71. Reprinted as Tech Memo 28, NRC, ACSSM, Ottawa, March 1954.

Emphasizes need for study of botanical relationships that have a bearing on cover type and subsurface features in organic terrain.

100. ————. 1954. PALAEOBOTANICAL METHOD IN THE PREDICTION OF SUBSURFACE SUMMER ICE CONDITIONS IN NORTHERN ORGANIC TERRAIN. Trans Roy Soc Canada 48 (series III): 51-64. Reprinted as Tech Memo 34, NRCC, ACSSM, Ottawa, Mar. 1955.

Discusses the relationships between permafrost, ice-formed terrain, and northern organic terrain and vegetation.

101. ————. 1955. ORGANIC TERRAIN ORGANIZATION FROM THE AIR (ALTITUDES LESS THAN 1,000 FEET). Handbook No. 1, Defence Research Board, Dept Natl Defence, Ottawa.

A photointerpretive study of muskeg using large-scale aerial photographs. Typical organic terrain features are shown as seen in both aerial and ground photographs. Stresses importance of properly assessing subsurface conditions, and includes classifications of summer subsurface ice conditions and subsurface terrain structure.

102. ————. 1955b. RANGE OF STRUCTURAL VARIATION IN ORGANIC TERRAIN. Trans Roy Soc Canada 49 (series III): 51-67. Reprinted as Tech Memo 39, NRCC, ACSSM, Ottawa, Mar. 1956.

Discusses macroscopic variations in organic terrain and the relationship of peaty constituents to its resistance to compressional forces.

103. ————. 1956a. THE APPLICATION OF AERIAL SURVEY OVER ORGANIC TERRAIN. Roads and Engr Constr, Aug. 1956.

Shows air-form patterns as seen from 30,000 feet. Author states these can be correlated with "low altitude experience", particularly to indicate ease of access to undeveloped areas.

104. ————. 1956b. MUSKEG ACCESS, WITH SPECIAL REFERENCE TO PROBLEMS OF THE PETROLEUM INDUSTRY. Canadian Mining and Metal Bull, Jul. 1956. Reprinted as Tech Memo 43, NRCC, ACSSM, Ottawa, Nov. 1956.

A review of the author's previous work on classification of muskeg and its recognition from the air, with suggestions for planning field operations.

105. ————. 1956c. PEAT IN CANADA AND BRITAIN--ECONOMIC IMPLICATIONS. J Roy Soc Arts 104: 968-979. Reprinted as Tech Memo 45, NRCC, ACSSM, Ottawa, Mar. 1957.

A comparison of "peat-lands" in Great Britain and "muskeg" in Canada, with a review of Canadian research.

106. ————. 1958. ORGANIC TERRAIN ORGANIZATION FROM THE AIR (ALTITUDES 1,000 TO 5,000 FEET). Handbook No. 2, Defence Research Board, Dept Natl Defence, Ottawa.

A continuation of photointerpretive studies explained in Handbook No. 1, with classification of form and tone categories. Photographs show various cover and terrain types at 5,000 feet, 1,000 feet, and ground level.

107. ———— and Jean M. Evel. 1958. MUSKEG IMPEDENCE FACTORS CONTROLLING VEHICLE MOBILITY. Canadian Oil and Gas Ind, July 1958. Reprinted as Tech Memo 57, NRCC, ACSSM, Ottawa, Feb. 1959.

Reviews problems of vehicular access over muskeg during periods of thaw. Includes requirements for design of vehicles.

108. ————. 1959. MOBILITY ON THE MUSKEG FRONTIERS. Engr J, July 1959.

A good, brief discussion of operational difficulties on muskeg, slightly obscured by introduction of unfamiliar terms.

109. ———— and I. C. MacFarlane. 1957. CORRELATION OF PALAEOBOTANICAL AND ENGINEERING STUDIES OF MUSKEG (PEAT) IN CANADA. Proc Fourth International Conf Soil Mechan and Foundation Engr, London 1a/23: 93-97. Reprinted as Research Paper No. 35, DBR, NRCC, Ottawa.

A review of earlier works, stressing need for linking studies of the mechanical properties of muskeg to Radforth's system of classification.

110. Ratcliffe, D. A. and D. Walker. 1958. THE SILVER FLOWE, GALLOWAY, SCOTLAND. J Ecol 46: 407-445.

A description and history of a series of bogs ranging from blanket bog to "high moor".

111. Rigg, George B. 1916. A SUMMARY OF BOG THEORIES. Plant World 19: 310-325.

A survey of literature on the exclusion from bogs of plants other than those normal to them.

112. ————. 1917. FOREST SUCCESSION AND RATE OF GROWTH IN SPHAGNUM BOGS. J Forestry 15: 726-739.

113. ————. 1925. SOME SPHAGNUM BOGS OF THE NORTH PACIFIC COAST OF AMERICA. Ecol 6: 260-278.

Cites evidence of advance of bog into forest. Regional description not attempted.

114. ————. 1937. SOME RAISED BOGS OF SOUTHEASTERN ALASKA, WITH NOTES ON FLAT BOGS AND MUSKEGS. Amer J Botany 24: 194-198.

115. ————. 1940a. COMPARISONS OF THE DEVELOPMENT OF SOME SPHAGNUM BOGS OF THE ATLANTIC COAST, THE INTERIOR, AND THE PACIFIC COAST. Am J Botany 27: 1-14.

116. ————. 1940b. THE DEVELOPMENT OF SPHAGNUM BOGS IN NORTH AMERICA. Botan Rev 6: 666-693.

A survey of the American literature.

117. ————. 1951. THE DEVELOPMENT OF SPHAGNUM BOGS IN NORTH AMERICA, II. Botan Rev 17: 109-131.

A continuation of the above.

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